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GRAVIMETRIC MAPS
OF THE
CENTRAL AFRICAN REPUBLIC
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SPECIAL REPORT

INTRODUCTION

This note presents the gravimetric maps of the Central African Republic. They consist of:

1) A map of Bouguer anomalies at 1/1,000,000 in two sections (eastern sheet, western sheet). This does not cover all of the territory of the Central African Republic, in particular to the east where measurements could not be made due to a lack of passable roads.

2) A map, in color, of Bouguer anomalies at 1/2,000,000, equally incomplete to the east, but to which have been incorporated the measurements made in the Cameroon (F. Collignon, 1969) and in Chad (p. Louis, 1970).

FIELD WORK

Historical

Close to 7,000 measuring stations have been occupied during several expeditions in which the following have participated:

--from 1960 to 1962 in Chad: M. Chauvin, P. Maillard, R. Dumas
--from 1969 to 1971 in the Central African Republic: M. Chauvin
--from 1975 to 1976 in the Central African Republic: M. Chauvin
and J. Vassal.

The measurements were made in accordance with the methods already used by the gravimetric reconnaissance surveys of ORSTOM in Central Africa (Y. Crenn, 1957) and Western Africa (Y. Crenn, J. Rechenmann, 1965).

For gravity measurements the following gravimeters were used: Worden (1960-1962), North American (1969-1971), and Lacoste-Romberg (1975-1976). Altitude determination by barometric leveling was done with Wallace-Tiernan altimeters.

Density, Coordinates, and Altitude of Stations

Most of the measurements were made along the side of roads and passable trails. Even when roads are lacking, a good number of stations are accessible by car since vegetation is rare and the ground fairly level.

Occasionally the operators had to go on foot, in particular in the N'Dele region, or by canoe, using the Ubangi or the Baminigi rivers in the north and the Sangha in the south-west of Bangui.

The mean density of the measurements is on the order of 100 per square degree. The distance which separates two neighboring stations on the same itinerary is about 3 km. The itineraries are separated by about thirty kilometers, sometimes less in the areas where the density reaches 150 points per square degree and even more in Chad. But often the distance increases in the eastern regions, not very accessible, where the density of the stations can be less than 50 per square degree.

When the itinerary follows a road shown on the map of 1/200,000 [sic], the distance covered is known by the vehicle's mileage indicator, the station easily located, and its coordinates determined with precision.

It is sometimes necessary to proceed with a plane table and a compass, the distances being measured with the help of the mileage indicator or of a calibrated wheel if one goes on foot. In this case, the itinerary is located, whenever possible, by means of the landmarks shown on the map (astronomical points, remarkable topographical features).

Depending on the difficulties encountered, the error in establishing the coordinates of a station can vary from 0.1° to 1° .

Determining the station's altitude by barometric levelling creates a relative error of less than 5 m in the altitude of two neighboring stations. The absolute error for one place or group of places can be as high as 10 m, sometimes 15 if conditions are unfavorable.

Altitude error is negligible when the station is located close to a benchmark of general levelling.

BOUGUER ANOMALIES

The Bouguer anomaly is defined by the expression:

$$B = G - (G_0 - C_z - T) \text{ where}$$

G = the observed gravity value

G_0 = the theoretical gravity value at the point of the reference ellipsoid corresponding to the station

C_z = the Bouguer correction

T = topographical correction

OBSERVED VALUE

This is equal to $G = G_r + \Delta G$ where:

G_r is the gravity value in a station adopted as a reference point.

ΔG is the measure of the difference of gravity between the reference station and any other station.

The reference value is that of one of the stations, cited in the appendix, of the network established in 1951-1952 by Martin et al, 1954, connected to the Paris-Observatory base point. The error which affects this value entails a systematically equal error on all measurements: we have therefore ignored it.

Gravimeters used for the measurement of ΔG are regularly calibrated at the departure and on the return of an expedition by repeated measurements on the calibration base of Bangui "Cathedral cornice", whose values differ by about 30 milligals.

The values of ΔG are corrected by the luni-solar tides and by a drift measured by succeeding stations on one point. This drift, assumed linear in time, varies from one piece of equipment to another and according to the conditions of transportation, of temperature, etc.

We acknowledge that the error committed on G , created by imprecise calibration or an incorrect estimation of drift, is on the order of several tens of milligals.

THEORETICAL VALUE

This is defined in the classic Potsdam system (1930) by the formula which gives G_0 in function of the latitude φ :

$$G_0 = 978049 (1 + 0.0052884 \sin^2 \varphi - 0.0000059 \sin^2 2\varphi).$$

With the new reference system called IGSN 71 (*), the
AIG (**) recommends the use of the formula established in 1967:

$$G_0 = 978031.8 (1 + 0.0053024 \sin^2 \varphi - 0.0000022 \sin^2 2\varphi).$$

We preferred to preserve the Potsdam system in order to
guard the homogeneity of all the gravimetric surveys carried
out by ORSTOM in Africa.

The values can be converted into the IGSN system by using
the formula established by the International Gravimetric Bureau (1976):

$$G_{IGSN71} = G_{Potsdam} - 17.696 + 1.227 \cdot 10^{-3} (G_{Potsdam} - 978,500.00)$$

The error of 1° in the latitude of a station entails an
error of between 0.2 mgal ($\varphi = 3^\circ$) and 0.5 mgal ($\varphi = 10^\circ$) on the
value G_0

BOUGUER CORRECTION

This is the sum of an agreed on free air corrections:

$$C_1 \text{ (mgal)} = 0.3086 * Z$$

and of a plateau correction:

$$C_2 \text{ (mgal)} = -0.0419 * d * Z$$

where d is the density of the terrain and Z is the altitude of the
station expressed in meters.

For the reasons of homogeneity already mentioned, $d = 2.67$
has been adopted for all stations where:

$$C_2 = 0.1967 * Z \text{ milligals.}$$

The imprecision of barometric levelling entails an error in C_2
usually less than 1 mgal, but which can reach 2 or 3 mgal in
unfavorable circumstances.

(*) International Gravity Standardization Network.

(**) Association Internationale de Géodésie de l'UGGI

TOPOGRAPHICAL CORRECTION

This correction takes into account the topography around the station. This was not done due to a lack of good hypsometric maps. Taking into account the fairly level terrain of the Central African Republic, this omitted correction usually remains less than 1 mgal.

To sum up, it can be said that at each point the Bouguer anomaly is the difference between the gravity and that of a model obtained by superimposing the ellipsoid and the topography affected by a constant density (Naudy et Neumann, 1965). The value of the anomaly at each point is subject to a maximum error of 5 mgal under the worst conditions; most of the time the error remains less than 3 mgal.

MAP AT 1/1,000,000

Aside from the principal cities all the itineraries and the value of the Bouguer anomaly at each measuring station have been shown.

The contour lines have been drawn from 10 to 10 milligals to the closest observed value, that is, without approximation. The reader will take into account the density of the station in the neighborhood of a contour line in order to appreciate the cogency of the drawing.

A map at 1/5,000,000 was also worked out with isostatic corrections calculated with the Airy hypothesis and a compensation depth of 30 km which gives the weakest isostatic anomalies.

MAP AT 1/2,000,000

In order to permit subsequent calculation of three-dimensional models for the interpretation of the principal anomalies, the values of the Bouguer anomaly were interpolated at the intersections of a grid.

Principals of the method

The works of M. LaPorte, 1962, concerning the automatic drawing of gravimetric maps, were used as a model.

The experimental anomaly $g(x,y)$ only being known at a certain number of points $A_1(x_1, y_1)$ at irregular intervals, it is necessary to establish a mathematical process which attributes a value G_M to each point M on the (x,y) coordinate. To do this, within an area surrounding a point M, one takes the points A_1 at coordinates (X_1, Y_1) , measured from the M taken as the beginning, and one defines a function $G(X,Y)$.

Take, for example:

$$G(X,Y) = G_M + aX + bY + cX^2 + dY^2 + eXY$$

One causes the coefficients G_M, a, b, c, d, e to be such that the function completely reproduces the G_1 values measured at points A_1 , assuming a weight P_1 as large as A_1 is close to M:

if $\epsilon_1 = G_1 - G_1$ this condition is written:

$$\sum P_1 \epsilon_1^2 \text{ minimized in a least squares sense.}$$

The interpolated value at point M on the (x,y) coordinates is thus:

$$G(0,0) = G_M$$

Choice of mathematical parameters

The measuring stations are located by the geographical coordinates expressed in degrees and minutes. In order to simplify the mathematical calculations, the interpolated points are located within the same system and distributed every ten minutes of longitude and of latitude. The latitudes being everywhere below 11° , the areas can be considered as squares without this leading to appreciable errors in the final calculations of the model. The dimensions of each area are weighted by the mean density of the measurements (100/square degree).

The choice of the dimensions of the zone, within which the observed values were used for the calculations, brought up several problems. Theoretically, several points (whose number must be greater than that of the coefficients of the $G(X,Y)$ function in order to justify the calculation by least squares) are sufficient to arrive at an interpolation. If too large an area is taken, there is an excessive number of points of which the most distant have almost no effect. Inversely, the choice of a zone with small dimensions runs the risk of obtaining an insufficient amount of data in the areas where the density of the stations is weak. Without totally escaping this dilemma, a "square" zone of $40' \times 40'$ was chosen, at the center of which was placed the interpolated point.

The best results were obtained with the first degree function $G(X,Y) = G_0 + aX + bY$. In this case the calculations can be carried out if within the zone there are a number of experimental values at least equal to 4.

The weight function is in the form $P_i = \left(\frac{R^2 - d_i^2}{d_i^2} \right)^n$ where R is the demi-diagonal of the square and d_i the distance from the center to the measuring station.

In order to avoid $P_i \rightarrow \infty$ when a station coincides with the interpolated point, $P_i = \left(\frac{R^2 - d_i^2}{d_i^2 + \eta^2} \right)^n$ was finally adopted, arbitrarily saying $\eta = 0.040$.

Finally the exponent n was assigned a value of 2 as M. LaPorte recommended.

The method does not allow the evaluation of the maximum error inherent in each interpolated value. The results can nevertheless be validated by considering the deviation between the interpolated value and the nearest experimental value. When there are measuring stations in the immediate neighborhood of the interpolated point, the deviation is small, on the order of several milligals. It may be greater where the distance increases or if the gradient rises. The calculation sometimes produces aberrant results when the experimental stations are poorly distributed or badly aligned. In such cases, it is necessary to arrive at a new interpolation using neighboring values already retained so that local parasitic anomalies will not show up, and one thus obtains a pseudo-regional value. On the other hand, in regions where the density of stations is high, the weight function gives the interpolated value a local character, in spite of the relatively large dimensions of the zone used for the calculations.

The network of interpolated values thus arrived at allowed us to use Meudon's 360/65 computer to carry out the drawing of contour lines from 10 to 10 milligals with the help of a program due to P. Stoclet (INAG). The curves were slightly adjusted to eliminate some angular points created by imperfections in the calculation program.

As a general rule, it can be said that the automatic drawing does not differ at all from drawing by hand in the areas where the stations are numerous, which justifies a posteriori the method used and the choice of mathematical parameters. Still, it is necessary to take note of some differences in the regions where the measurements are few or poorly distributed, but one must admit that no interpolation, whether manual or automatic, can ever replace measurements in the field.

APPENDIX

List of gravimetric bases of the general network of Martin et al.
Central African Republic and Chad

Station names: Sahr airport (Chad) n° 177
Lat. : 09° 09'5 N Altitude : 364m
Long. : 18° 24'7 E Gravity : 978,037.84mgal

Description: airport 1km west-north-west of the town of Fort-Archambault. Station inside the large hangar of the airport, beside the wall to the right in coming from the plane parking area, about 15 meters in front of and 2.50 meters to the left of the map painted on the wall

Station names: Bouar airport (C.A.R.) n° 181
Lat. : 06° 00'4 N Altitude : 1,000m
Long. : 15° 33'9 E Gravity : 977,818.05mgal

Description: in the middle of the runway, facing the Air France terminal and the wind-sock (N.B. the airport is about 8 km to the north of Bouar).

Station names: Berberati airport (C.A.R.) n° 182
Lat. : 04° 15'3 N Altitude : 607m (?)
Long. : 15° 47'6E Gravity : 977,910.13mgal

Description: at the far north of the runway, on a white line in the cement, between the two corners at the end of the runway

Station names: Bangui weather station (C.A.R.) n° 184
Lat. : 04° 22'5 N Altitude : 385.6m
Long. : 18° 22'5 E Gravity : 977,913.73mgal
Description: weather station, outside, at the foot of a square
pillar next to the one bearing the levelling benchmark
n° 1 and facing this benchmark. Station 57 cm below
benchmark.

Station names: Bangui, cathedral (C.A.R.) n° 185
Lat. : 04° 22'2 N Altitude : 368.5m
Long. : 18° 34'9 E Gravity : 977,917.95mgal
Description: Cathedral. Station beside the facade, to the right
of the porch, on the middle landing of the steps, above
the first five steps. Station 1 cm above benchmark n° 14.

Station names: Bangui, City Hall (C.A.R.) n° 186
Lat. : 04° 21'8 N Altitude: 354.5m
Long. : 18° 35'2 E Gravity: 977,920.95mgal
Description: Station on the steps of the town hall, in the door
opening on the right, next to the right riser, in close
proximity to levelling benchmark n° 13. Station 21cm
below benchmark.

Station names: Bangui, ORSTOM (C.A.R.) n° 189
Lat. : 04° 26'2 N Altitude : 387.4m
Long. : 18° 32'6 E Gravity: 977,918.85mgal
Description: 10 km along the road leaving Bangui towards the N.N.W.
(the road going to Fort-Lamy). The buildings of the
Office de la Recherche Scientifique Outre-Mer, Institut
d'Etudes Centrafricaines, to the right of the road coming

from Bangui. Pavillon covered with bamboo tiles, under the veranda, at the extreme left of the main facade.

Diagram.

Station name: Bambari, airport (C.A.R.) n° 190
Lat. : 05° 50'5 N Altitude : 450m (?)
Long. : 20° 37'3 E Gravity: 977,922.0mgal
Description: on the runway; on its axis and at about 270m from its most western point. N.B. This is a new section of Bambari, located about 15 km to the N.N.W. of the town.

Station name: Bria, airport (C.A.R.) n° 191
Lat. : 06° 31'7 N Altitude : 619m (?)
Long. : 21°59'5 E Gravity : 977,927.00mgal
Description: On the runway, on its axis and 7m from the white line marking the eastern edge.

Station name: Bangassou, airport n° 192
Lat. : 04° 44'5 N Altitude : 492m
Long. : 22° 50'2 E Gravity : 977,916.85mgal
Description: In the plane parking area, about 50m S.E. of the gas storage shed.

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